OUTLOOK FOR THE FUTURE

Land Sensing Satellites in the Year 2000

A paper presented at the
International Geoscience and Remote Sensing Symposium (IGARSS),
Singapore, August 7, 1997

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In the year 2000, if all the current plans for earth viewing satellites come to pass, there will be 31 satellites capable of providing data of 30 meters or better resolution in orbit at the same time. 14 of these will be privately funded by US corporations, all with resolutions of 10 meters or better. 8 optical systems and 2 radar satellites will be funded by foreign countries. The US government will launch 2 multispectral systems and 3 hyperspectral satellites by then. While it is probable that the reality will not be as bountiful as the plans indicate, it is certain that the number of high resolution satellites in operation will be significantly greater than the current supply.

This paper presents a summary of the high resolution systems currently planned to be operating in the year 2000. The systems can be usefully classified into four groups, (a) broad area coverage, 5 to 30 meters resolution and multiple color bands, (b) narrow swaths, 1 meter or less panchromatic resolution, and VNIR color only, (c) Hyperspectral sensors with 30 meter resolution and (d) Radar with 5 to 10 meter resolution. Their capabilities are described and compared in detail, including their spectral bands and resolutions, and their coverage capacity.

Purpose

This paper provides an overview of the explosion in land observing satellites planned for the next decade. It is intended as a wake-up call and planning tool for all who are interested in knowing and keeping track of the details of what is going on with the surface of our planet and in particular for those who are developing the skills to measure and understand the breadth and detail of the information that analysis of the satellite data could make available to us for the first time. The amount and quality of the land information data which the land observing satellite fleet in 2000 will be capable of providing could revolutionize both our scientific knowledge and our practical management of our earth's resources. The satellites are however only the first step. Their value can only be realized through the ingenuity and efforts of the users.

The Satellites

Among the many predictions for the new millennium are the orbiting of 31 satellites in polar orbit providing land cover data at resolutions of one to thirty meters. These satellites are summarized in figure 1, the program names, system funders and launch dates are presented in figure 2 and their launch and operational schedules are presented in figure 3. They fall into four functionally separate classes.

Landsat-like: The thirteen Landsat-like satellites have the middle resolution, broad area and multispectral coverage characteristic of the current satellites, Landsat, SPOT and IRS. These current programs are being extended and expanded. As can be seen on figure 3, the Indian program, with plans for the flight of four satellites through this period is the most operationally robust of the government group. The group will be joined by two satellites created by a cooperative program between China and Brazil and one, four satellite, private system.

High Resolution: The twelve high resolution systems will provide an order of magnitude improvement in ground resolution, at the expense of less area and multispectral capability. With the exception of one Indian and one Russian satellite, these satellites are all funded and operated by private corporations. The almost exclusive interest of the private sector investors in the high resolution systems indicates their belief that this is the space capability required to create commercially valuable information products.

Hyperspectral: The three government funded hyperspectral satellites and the proposed private system will explore the potential for the development of new multispectral analysis based applications by providing near continuous radiometry over the visible, near IR and short wave IR spectrum.

Radar: The current Canadian and ESA radar programs will be continued into this period as well. Radar's all weather capability makes it the instrument of necessity for many observational problems and it will become increasingly valuable for general problems as better techniques for analysis are developed, including the integration of radar and optical data.

Technical Overview

The best way to understand the scope and variety of the data which will be available from the new millennium fleet is to look at the three principal observational dimensions of its data, ground resolution, land coverage frequency and spectral coverage. They are tied together in sometimes unfortunate ways, (from the user's point of view), by the laws of optics, orbital mechanics and the ultimate decision maker, economics. No one system can provide all the measurement features needed by the user community.

The following discussion will present three summary maps of the data scope and variation which will be provided by the 31 satellites; land coverage and ground resolution, the spectral position of measured bands and the ground resolution of each band.

Land coverage and ground resolution: All but two of the satellites will cover the total land mass since they are in polar sun synchronous orbit. The two exceptions are SPIN-2 which is in a 65 degree orbit and QuickBird for which a 52 degree orbit inclination is being considered.

Land coverage frequency must be considered in two ways, the frequency with which the system can provide images of the total globe, and the time it takes to revisit a given site. Because global coverage frequency is inversely proportional to the sensor's ground field of view or swath width, this parameter will be presented as one measure of coverage capability in the following discussion.

Figure 4 presents the ground resolution and the ground swath width for all of the satellites noted above. This plot provides a graphic illustration of the difference in coverage and resolution between the four classes of satellites. Only two sensors escape the boxes. The IRS C,D Pan sensor flies on a satellite that is in the Landsat-like box, but lies outside that category because it sacrifices swath width for its higher resolution. However, it can be pointed off the orbit path which allows 2 to 4 day revisits to specific sites. SPIN-2's escape from its box is described below.

The Landsat-like group:

The Landsat-type satellites are designed to provide fairly frequent global coverage by choosing the sensor ground swath and orbit parameters so that they will cover the complete equatorial surface each orbital repeat cycle. The current and planned satellites achieve this by having ground swaths between 120 and 200 kilometers. Their orbital periods and thus global coverage times, vary from 16 days for Landsat to 22, 24, and 26 days for the Indian, French and China/Brazilian satellites. Taking singly, even these repeat cycles are too long for many applications. However, the similarity of the sensor data from the 12 satellites in this group can, for many applications, make it possible to use the data from all of the satellites interchangeably and thus have available the one to seven day coverage rates illustrated on figure 5.

Figure 5 shows the number of the Landsat-like satellites that you could see (or more precisely the number of satellites that could see you at an equatorial [1] site) on any day over a randomly selected 100 day period for the three satellites now in orbit, for the 8 government satellites in orbit in the year 2000, and for the 12 satellite fleet [2] resulting from adding the four Resource21 birds. The aperiodic nature of the second plot cries out for effective international cooperation to optimize the spacing of the coverage opportunities. (There is no indication that this is likely to happen).

The High Resolution Group: The much narrower ground swaths of the high resolution sensors, 4 to 36 kilometers, can only achieve total global coverage in periods ranging from 4 months to 2 years. Since the high resolution sensors being planned generate communication rates between 20 to 100 times that of Landsat this design limitation is caused by the practical and economic limits of the data collection systems. SPIN 2 avoids this problem since its data collection system is film return which places it in its unique position on the chart. However, for many users the good news is that the satellites are designed to be capable of quickly pointing off nadir and thus can see any given site in 2 to 4 days. Thus, even two high resolution satellites properly synchronized could provide daily repeat coverage nearly anywhere.

WARNING-Clouds severely effect the above quoted repeat times: The above discussion of the repeat times should not be used without at least doubling the numbers quoted to provide some sense of the effect of clouds on the actual ability to get cloud free images, i.e. to actually see the desired targets. Figure 6 presents the results of a simulation which recorded the best cloud free percentage images for each Landsat WRS site [3] collected over a 16 day period in early spring by using one, two, three and four satellites orbiting over a WRS grid containing the % of cloud cover in 5% increments for every day of the year [4].

The fact is plain, our planet is cloudy and the clouds obstruct our satellite land view more than we would like for many of our time critical applications. The message is equally plain, multiple satellites (or radar) are required if we need assured land coverage in short time periods of weeks to months. (Note the four maps also represent very closely the collection capabilities of one satellite for 16, 32, 48 and 64 days.) As the maps make plain, the problem is geographically focused and as would be expected the agricultural belts, where frequent data are most required, are the cloudiest. It remains to be seen whether the small target areas and pointability of the high resolution systems will provide higher cloud-free data returns than those calculated for the large area non-pointing systems illustrated above.

The Hyperspectral Group: the US government is launching three satellites to test the full potential of multispectral analysis for the identification of both man-made and natural surface elements. Because of the very high data rates required by the hyperspectral sensors, the resolution of these systems has been restricted to thirty meters. There is also a sense that thirty meters may well be more than sufficient to characterize the majority of at least the natural targets, i.e. mineral and vegetative cover. The Australian government is stimulating interest in the private sector for the commercial development and operation of a near hyperspectral system, since the sensor uses two groups of 32 bands instead of the spectrometers of the other systems.

Radar: The current and proposed radar satellites can provide data in a variety of resolution, swath combinations. The values on the figure represent their high resolution capabilities. Again, the practical limits on data rate have been an important factor in their resolution/swath tradeoffs. It is beyond the scope of this paper to define the large range of resolution/coverage products available from these satellites and the potential user is urged to contact his friendly data supplier.

Spectral Coverage and Ground Resolution: Figure 7 presents the bands measured by each of the multispectral instruments. Figure 8 provides the resolution of each band. (The bands are listed under their Landsat 7 band counterparts).

The Landsat-like Group: As can be seen on figure 7, except for the EOS AM-1 ASTER instrument, the bands from all the satellites are very close to those used by Landsat. This is of course because the Landsat bands were placed in nearly all the wavelength windows free of severe atmospheric absorption. The Landsat-like satellites emphasize multispectral coverage, all of them having at least the lower SWIR band and three including both the upper SWIR and TIR bands. ASTER will provide even greater spectral definition in the upper SWIR and TIR regions.

It is important to note that all multispectral data may not be equally usable for all applications even when the same bands are available. For analysis that are critically dependent on measuring the absolute reflected radiation over years to decades, sensor calibration becomes a critical parameter. Landsat 7 and Resource21 systems will have sun and moon based calibration capabilities while the other systems will rely on internal lamps and ground targets for their calibration. Equally important to such applications is the ability to adjust the measured radiation for the varying atmospheric conditions. NASA is planning to operate Landsat 7 and AM-1 in very close proximity to measure the atmospheric input using an AM-1 sensor (MODIS).

As shown on figure 8, the multispectral resolutions range from ten to thirty meters with the exception of the six meter sensor on IRS-P5 and 2A which achieve their higher resolutions by reductions in swath width, (see figure 4). The panchromatic sensors of interest in this group range from 6 to 20 meters. Experience with integrating the ten meter panchromatic data and the twenty meter multispectral data from SPOT has shown the value for many applications of the use of the pan band in sharpening the color bands.

The High Resolution Group: In contrast to the Landsat-like group, half of this group has limited multispectral coverage, while the other half has none at all. It is obvious that as a group the critical measurement is the ground resolution which is essential for identifying man-made objects and for updating maps and GIS data bases. Whereas in the Landsat-like group the pan bands are used to sharpen the color bands, in this group the color bands will probably be used to add additional information to the pan band data.

The Hyperspectral Group: The hyperspectral satellites are being flown to explore the potential of using the full spectral response over the VNIR and SWIR spectrum. Note on figure 8, that hyperspectral is being defined as sensors with 32 to 256 bands per VNIR or SWIR range.

Radar: While the current and planned radar satellites will have only one frequency, they do have several polarization options and thus have a multidimensional analysis possibility analogous to the optical system's multispectral analysis. Again, the reader is advised to contact the radar data providers to get an understanding of the full range of data products their systems are capable of providing.

Data Availability: The good news is that there are plans for 31 satellites capable of providing a wide range of land data information products. The amount, sophistication and variety of the land data that COULD be available for analysis is staggering. It is probably equally good news that all the data, government and private, except Landsat 7 data, will be available commercially at market determined prices. It's even better news that current US law requires that Landsat 7 data be made available to all at the " cost of furnishing user requests". However, to be available the data must be first acquired. Landsat 7 is the only system which plans to acquire and archive multiple total land cover data sets each year. The other government systems will be collecting for their own purposes and for orders acquired by their commercial sales outlets. The private systems' acquisition plans will be totally market driven.

Why So Many Satellites?: 31 satellites may seem to be more than a few too many for needs of the earth observing community. Before making that judgment however, it may be useful to consider the following points.

As noted above, none of the planned satellites will provide all of the data characteristics needed by the broad range of user requirements. Thus at least four systems would be needed to provide the different data types the fleet is currently planning. The day of the battlestar galactica, single satellites with suites of many instruments, appears to be over [5].

The need for multiple satellites was also discussed in the section on coverage frequency, which emphasized the negative effects of the world's 50% cloud cover.. Resource21 is planning a four satellite system to meet their customers need for weekly observation of crop conditions. The Global Change Science goal of global of seasonal coverage requires a minimum of three to four satellites. The use of satellite data for disaster analysis and relief planning can be very effective but only if the satellite can acquire imagery almost immediately after the event, a possibility only if two or more pointable sensors are in orbit. For weather related disasters, radar is often the only system which can see the ground. Again multiple radar satellites would be required for sufficiently rapid coverage.

Finally there is the need to assure operational stability. In the last two years, two land observation satellites failed to make orbit, Landsat 6 and SPIN-2, and two failed on orbit prematurely, SPOT 3 and ADEOS. Obviously more than one system must be available to provide the operational assurance required if users are to be able to make the data a requirement for their activities. India, EarthWatch and Resource21 are planning operationally robust systems of four satellites each. CBERS and all of the high resolution satellite providers are planning two systems each.

Concluding remarks

This paper attempts to provide the best current information available on the world wide, public and private, plans for operating land observation satellites in the new millennium. it also provides charts summarizing the types of measurements and their parameter ranges the satellite/sensor fleet will be capable of providing. Much of the data presented in the previous charts have been combined and provided in a full service reference chart in figure 9.

[NOTE: Figure 9 is an Excel file.

Linking to the file will give you the opportunity to download the file to your system.
You will have to download the file and have a recent version of Excel (Version 5.0 or better for Mac) on your system to view it.
To download the file, press "SHIFT" ("OPTION" on a Mac) while selecting figure 9.]

The goal of the report is convince the land information user community and especially the so-called "value added" experts in industry and academia, that their cup is about to runneth over. The satellites are really coming, though probably not in the numbers presented in this paper. However half are government funded and most of these are in or on the path toward construction. If only half the proposed commercial satellites make orbit there will be 20 satellites in orbit in 2000.

The really big bucks, literally billions, required to create the satellite systems are being spent by both the public and private sectors.. It is now up to the users, public and private to invest in the development of the analysis technologies, the information products and the applications that will generate the dollars that will keep the new millennium satellites flying. The question is are you, they, anybody ready for the deluge?

NOTES

1. Since polar orbits cross near the polls and have constant width ground swaths, the ground overlap between orbits increases with latitude. At 60 degrees the overlap is 100% and thus the equatorial coverage rate doubles.
2. I have taken the liberty in the third plot of assuming that the two Indian satellite series will eventually be planned to have the same orbital period in order to create the advantage of a total periodic period of 6 days in place of the aperiodic 11 and 12 day periods currently quoted (which also assumes that the two satellites of each series are placed in orbits halving their 22 and 24 day return periods.)
3. The maps are the world as seen by the constant swath Landsat image and thus are greatly distorted at the higher latitudes. The Landsat World Reference System (WRS) maps the world in 30,107 185x170 kilometer squares.
4. The WRS cloud data were created by the Air Force from a global data set for the year 1977 and represent the cloud coverage at the 9:30 AM local crossing time of the Landsat satellite.
5. It is however worth noting that four of the Landsat-like systems, SPOT, IRS, CBERS and AM-1, do carry one or two other wide field of view sensors to provide daily to weekly coverage to supplement their main sensor data. (See notes and box on figure 9 for details).

The Regional Applications Center Program

A major barrier to the wider use of Earth remote sensing data is timely access to satellite data products that can be easily combined with other resource management applications already being carried out by the general user community. NASA's Regional Applications Center (RAC) development effort was initiated by the Goddard Space Flight Center's Applied Information Sciences Branch (sponsor of this Tutorial) to enable and greatly enhance NASA's Earth Sciences programs in education, commercial partnership, data usage, and public awareness requirements. RACs provide the capability to directly receive and manipulate localized (pertaining to areas relevant to and influenced by an RAC's region) satellite data inexpensively on a routine basis. The RAC Program resulted from a desire to make NASA-developed technologies available as well to the public sector.

RAC objectives are founded on an overall goal of fostering the self-supporting use of environmental and Earth science data by regional institutions including state and local government, universities, consortia, and commercial companies. These objectives include:

1. Promoting the establishment of self-sustaining public and private sector working relationships to broaden user access to NASA data.
2. Validating, refining, and transferring NASA technology through collaborative testbedding.
3. Incorporating RAC applied research results into shareable global environmental knowledge bases, and
4. Stimulating the development of associated commercial activities.

With respect to Earth science applications, algorithms implemented at each RAC provide a high degree of accuracy in mapping the satellite data to the regional geography within the RACs service area. One of the unique and innovative features of the information system being developed is its capability of supporting multiple-user points of view as well as allowing users to customize the system to represent their specific applications. Current plans call for RACs to be applied to agriculture, forest and wetlands inventories, environmental resource management applications, and public safety tied to prediction of possible weather-related alerts. More generally, these systems can help educate the public about the value and relevance of Earth-sensing satellite data.

In the spirit of inventing "new ways of doing business", the RAC concept represents a paradigm shift towards evolutionary, flexible, and cost-efficient information management techniques. The collaborative development and involvement of non-traditional users will make Earth science data easier to preserve, locate and access for regional applications.

A prime goal of the RAC program is to enfranchise the general public in the broader integration of Earth satellite data with localized data to address regional and environmental problems or issues, e.g., resource management, disaster relief, education, etc. The RAC system can also be of aid to commercial profit-making enterprises, e.g., agribusiness, insurance, oil exploration, weather forecasting, etc.

RAC's have the capacity to activate research and development leading to new services based on information management capabilities. They can serve as regional centers of excellence for a full range of remote sensing practice as well as for the evolvement and exploitation of information technologies. In addition to generating information products to support decision making and planning, such regional centers would invite participants and clients to share in global scientific and technical data, information, and knowledge through access to their own in-house technologies.

Commercialization of Space Remote Sensing

The shift from government programs for space platforms mounting remote sensors to programs devised and funded by private industry has been slow and only now, after 25 years since Landsat 1, has commercialization begun to take off. This contrasts with one of the first space programs developed by NASA aided by other federal agencies: namely, communications satellites, which with the incorporation of Comsat began in just a few years to assume a lead role in which development and funding from industry became the mainstay. Launch vehicles (i.e., rockets) also were built by commercial firms to put private satellites into space. For much of this period, earth resources satellites as well as most meteorological satellites remained the province of governmental sponsorship and control.

The success of the Landsats prompted other governments across the world to underwrite ventures into satellite remote sensing. Some of these branched into the private sector in time. The SPOT program developed by the French, with first launch in 1986, soon thereafter became the pervue of a commercial corporation. The Indian government began its IRS program in 1988. The European Space Agency (ESA) actuated its ERS-1 and -2 operational satellites beginning in 1990 as did the Japanese Space Agency (NASDA), with JERS-1 the same year. The Canadians entered the picture with their Radarsat in 1991. In all of these the governments developed and launched the satellites but either created or arranged with private corporations for the operation of the data gathering and distribution system. Perusal of some of the tables presented in this section indicates that governments are still key players in recent and impending launches of an ever-increasing variety of space platforms and sensor systems. But these tables also point to the expanding role of industry, as indicated by the planned launches of 4 or 5 privately funded satellites by the end of 1998. These satellites will provide for the first time the high resolution imagery which the industry believes is the key for economically successful earth sensing satellite ventures.

In the early days, the principal users of civilian remote sensing data (aside from the military who have always been involved in surveillance systems) in the U.S. were government agencies, state agencies, and academia. Gradually, industry came to recognize the basic value of the synoptic coverage afforded by space systems and started to purchase data in abundance.

To handle dissemination to all kinds of users, the Dept. of the Interior through its U.S. Geological Survey established the EROS Data Center in Sioux Falls, S.D. Its primary sales were a mix of Landsat data and aerial photography. NOAA continued to supply meteorological remote sensing output that rapidly began to effect forecasting and presentation of weather changes appearing in newspapers and on radio and TV.

A number of companies offering value added services, mainly to industry, emerged starting in the 1970s. One familiar to this writer is the Earthsat Corporation in Bethesda, MD, which could provide a wide range of capabilities including a full analysis of a given application problem. Others concentrated on providing software for image processing and analysis to be performed at the customer's facility. ERDAS in Atlanta, GA. was one of the first in this field. Many other software programs have been developed since the 1970s, some by commercial firms and others by universities (e.g., IDRISI, used in this Tutorial; developed in the Geography Department at Clark University). As GIS grew into a major means of handling geospatial data and solving problems related to siting, land use, environmental monitoring, etc. a few companies, such as ESRI (Environmental Systems Research Institute) and Arc/Info sprang up to offer services and since then many more have joined in providing powerful programs that convolve GIS operations with image processing tools.

Some indication of the breadth of services now available from commercial organizations can be garnered from at the lists and ads in the Green Book: Who's Who in the GeoTechnologies, published each year by EOM, Aurora, CO (http://www.eomonline.com).

The first push to privatize remote sensing is traceable to some key historical dates in the Landsat program. (This is treated in some detail in the Landsat Chronology put together by Ed Sheffner at the Ames Research Center [NASA], at: http://geo.arc.nasa.gov/sge/landsat/lpchron.html.) In 1979, NASA relinquished operation of its Landsats (Ls-3 had been launched by then) to NOAA. At the start of the Reagan administration, the drive for commercialization was accelerated. During 1984, the Dept. of Commerce set into motion procedures for privatizing remote sensing in those areas under conditions that did not conflict with military interests. Out of this, an agreement was reached in 1985 for the newly incorporated Eosat in Landover, MD, formed by Hughes and RCA, to operate the Landsat program for 10 years while EROS continued in its role as the National Archive for all land images. However, in 1992 a government decision was made to return the development and launching of Landsat-7 to the Dept. of Defense in cooperation with NASA; DoD opted out of the program by 1996 and Landsat-7 was dovetailed into the EOS/MPTE program. By 1996, however, Landsat-7 had reverted to NASA to operate, with its data to be distributed by an EOSDIS facility built at the EROS Data Cemter to handle the distribution of the multi-terrabytes of data that will ensue from the MPTE program. It is noteworthy that Landsat-7 will be the first satellite ever to be programmed to gather and archive complete global land scene sets several times a year. The commercial entities' policies are generally to acquire only scenes ordered by customers.

To assure that commercialization will continue on a parallel course with this and other government programs, an important workshop entitled The New Millenium Program was held at JPL in 1996 to foster coordination of government and private industry in those aspects of remote sensing that rely on expensive spacecraft to gather data.

The maturation of remote sensing probably began with the Eosat (now SpaceImaging-Eosat) Corp.'s assumption as a commercial enterprise. Attendance at any of the rather large number of annual meetings and conferences dealing with both research and applications in all aspects of remote sensing (two of the best known are the ERIM [Environmental Research Institute of Michigan] Conference and the 1-2 sponsored each year by the ASPRS [American Society of Photogrammetry and Remote Sensing) will reveal the growth of commercial remote sensing simply by touring the Exhibit Hall at each meeting. This is prima facie evidence that remote sensing is now recognized as a major venture capital investment whose potential for billions of dollars (worldwide) in business is now being realized. The entry of other nations as providers of remote sensing data shows that the marketplace is truly global. After all, everyone has a vested interest in monitoring the environment, searching for resources, assessing agricultural production, controlling the oceans' productivity, being constantly alert for dangerous weather conditions and climatic fluctuations, and generally knowing how the land and the seas are being used for (what's where).

BIG TIME REMOTE SENSING HAS ARRIVED!

Figure #1

31 Land Observation Satellites

Planned to be operating in the year 2000

- 13 Landsat-like satellites
  - 2, USG (1 with Japan)
  - 1, France
  - 4, India
  - 2, China & Brazil
  - 4, US Commercial (R21)
- 12 High Resolution
  - 8 with color from 4 US companies
  - 4 PAN only
    - 2, US/Israel company
    - 1, India
    - 1, Russia
- 4 Hyperspectral satellites
  - 3, USG
  - 1, Australia
- 2 Radar satellites
  - 1, ESA
  - 1, Canada

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Figure 2:
Land Imaging Satellites - The Next Five years

NOTE: The links listed in this table do not have
return links to this page.

PROGRAM	OWNER	LAUNCH
Landsat-like		
IRS-1 C,D	India (gov.)	'95, '97
IRS-P5, IRS-2A	India (gov.)	'98, '99
Spot 4	France (gov.)	'97
CBERS 1,2	China/Brazil (gov.)	'98, '99
Landsat 7	U.S. (gov.)	'98
EOS AM-1	U.S./Japan (gov.)	'98
R21, A-D	Resource 21	4 in '00
High Resolution		
EarlyBird 1,2	EarthWatch	'97, '98
IKONOS 1,2	Space Imaging EOSAT	'98, '99
QuickBird 1,2	EarthWatch	'98, '99
OrbView-3,4	Orbimage	'98, '99
SPIN-2, A,B	Russia (gov.)	'98, '99
EROS-A,B	West Ind. Space (Israel/US)	'98, '99
IRS-P6 (CARTOSAT-1)	India (gov.)	'99
Hyperspectral		
TRW Lewis	U.S. (gov.)	'97

EO-1	U.S. (gov.)	'99
HRST	U.S. (gov.)	'00
ARIES	Australia	'00

RADAR

Radarsat	Canada (gov.)	'95
Envisat	ESA (gov.)	'99

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Figure 3:
Launch and Operational Schedules Through 2002

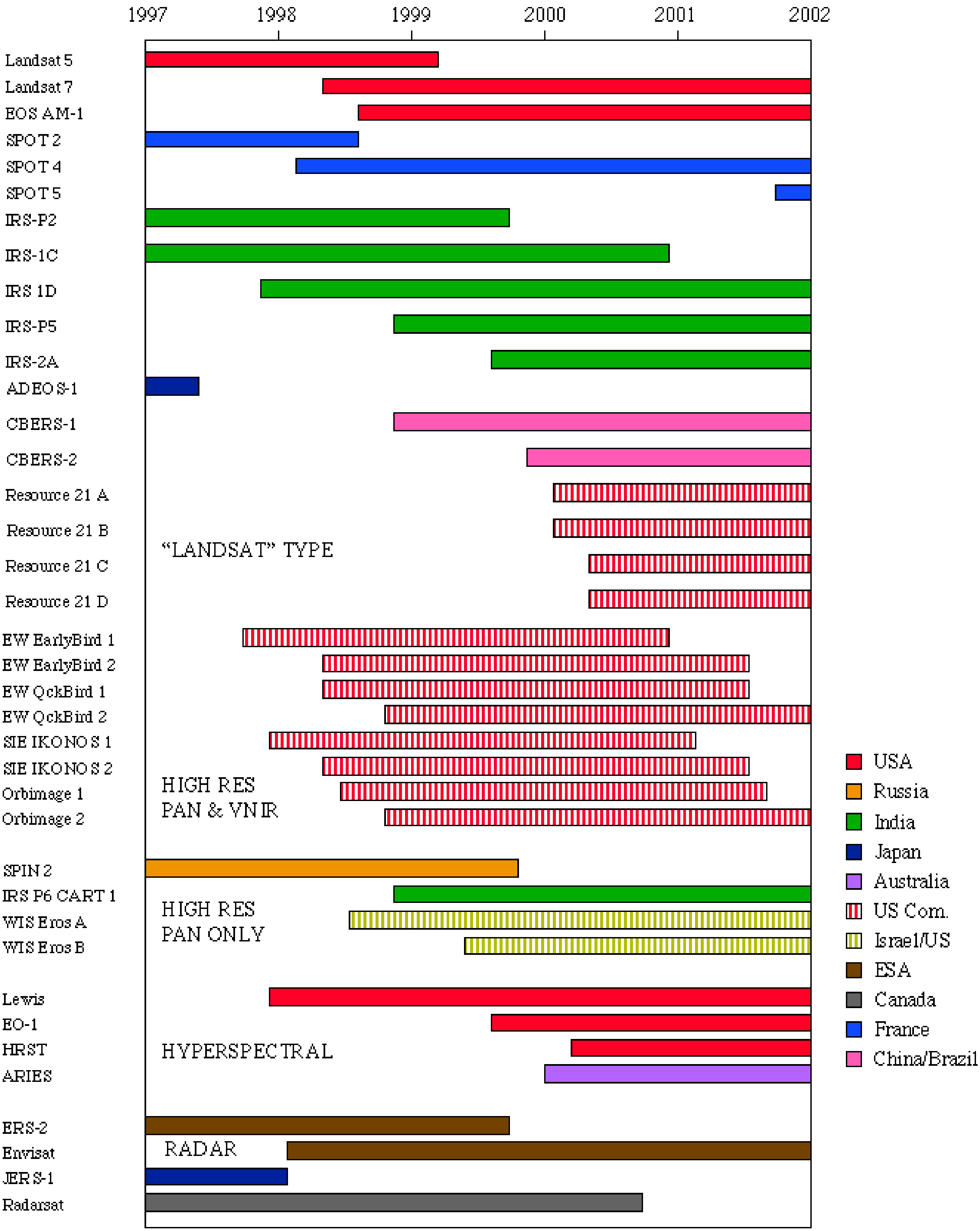

Figure 4:
Land Observation Satellites - Ground Resolution vs. Swath Width

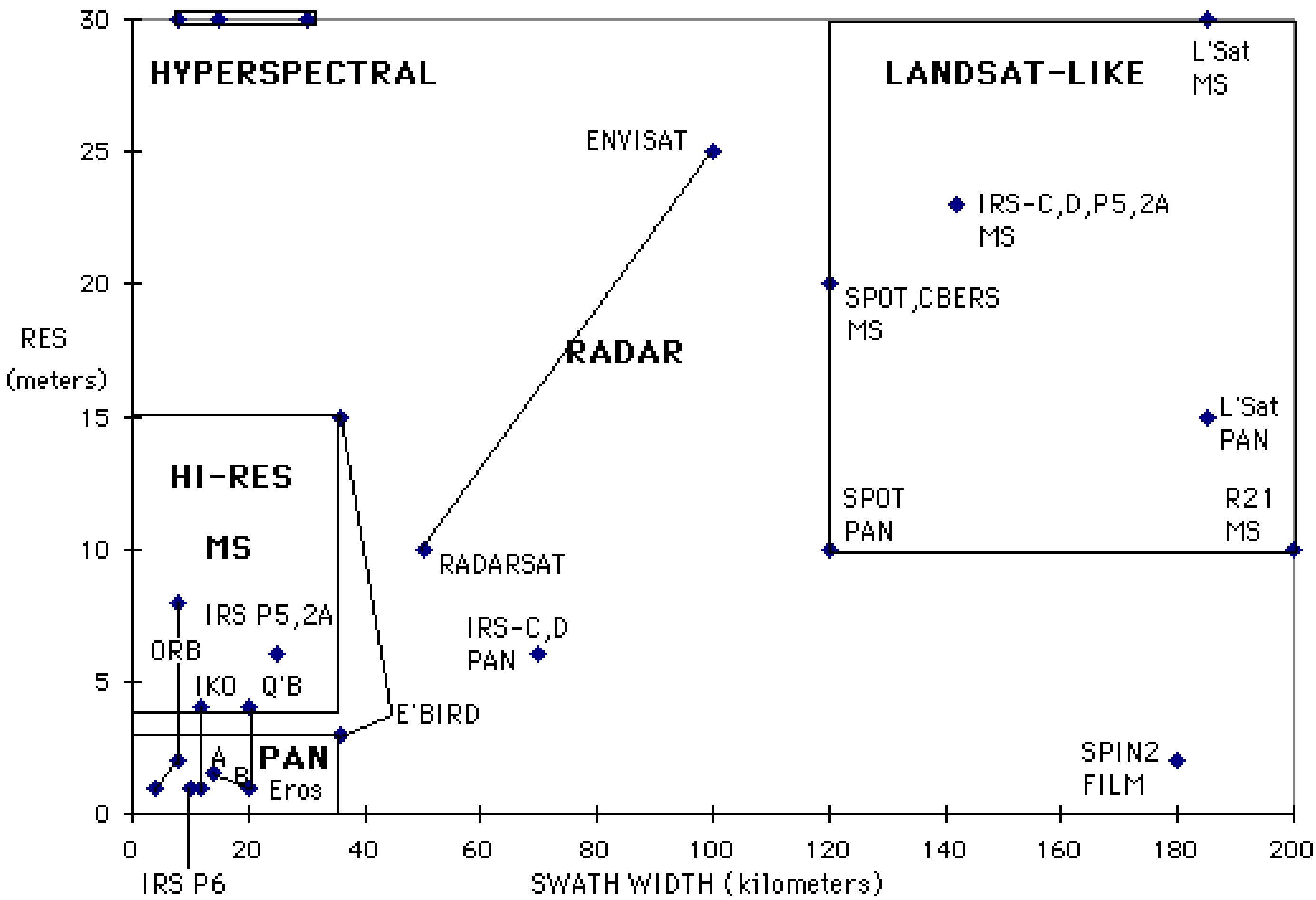

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Figure 5:
Hundred Day Coverage Cycle for Landsat-type Satellites:
Now and 2000

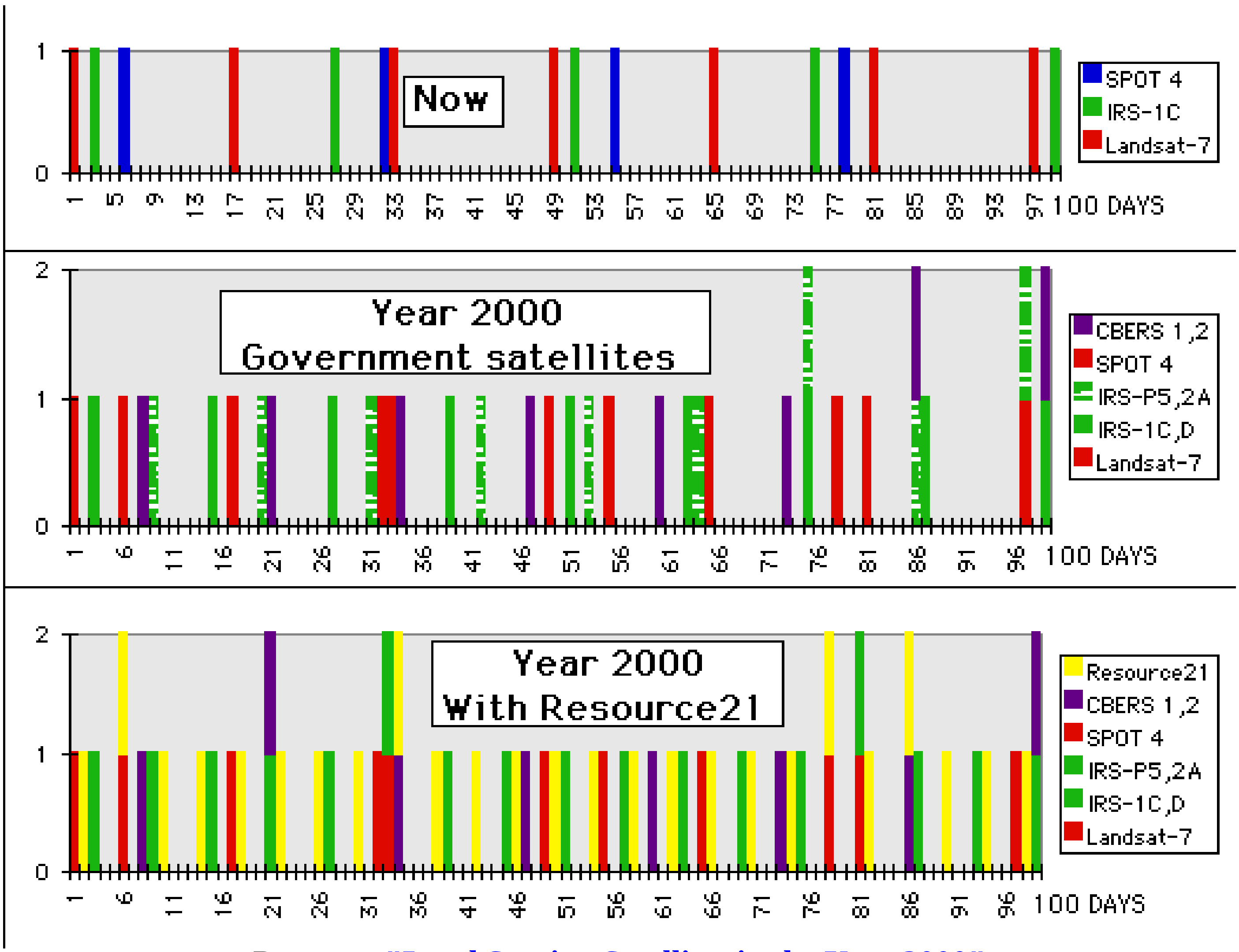

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Figure 6: Cloud free percentage images for each Landsat WRS site collected over a 16 day period in early spring using one, two, three and four satellites orbiting over a WRS grid

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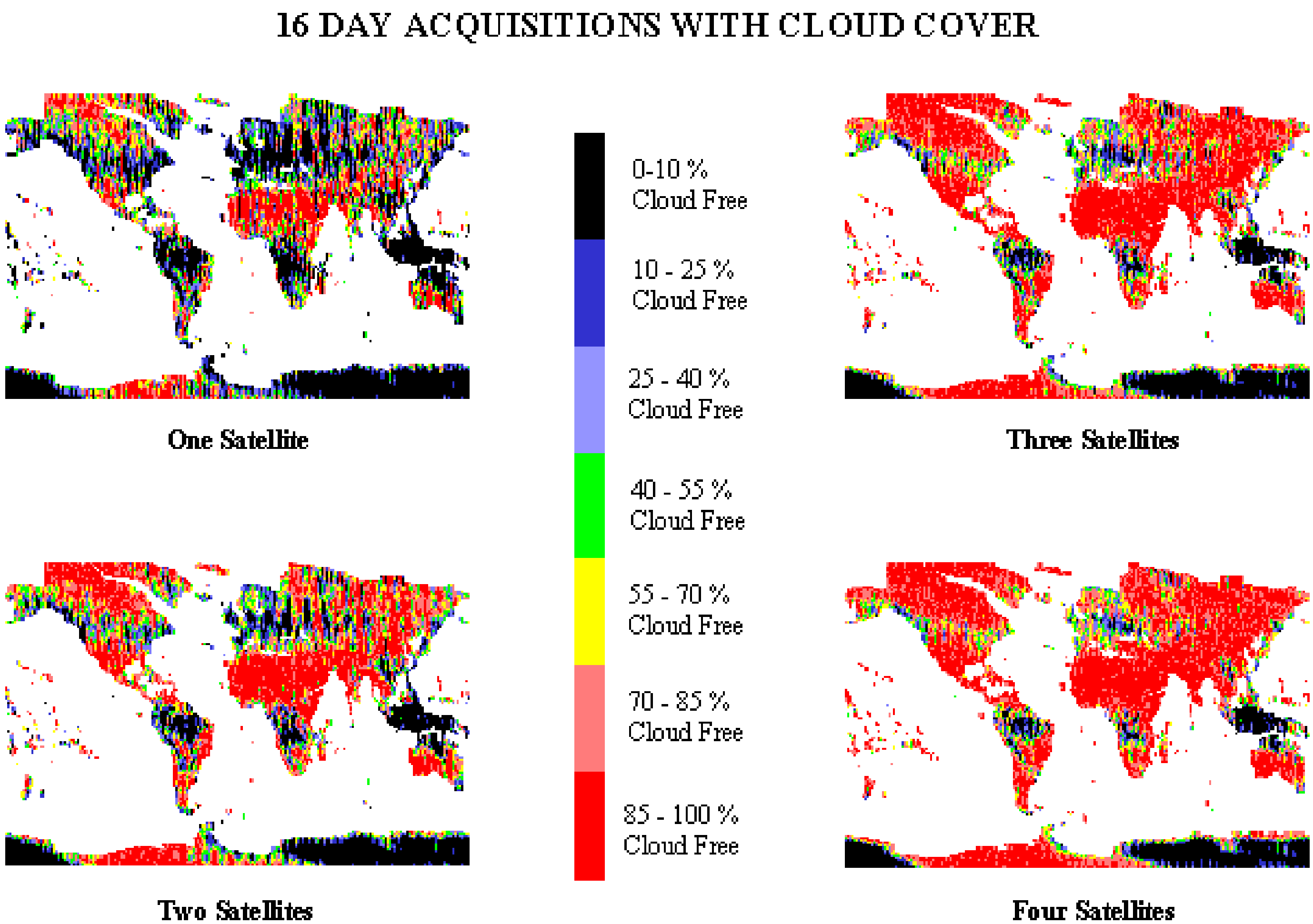

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Figure 7:
Band Comparison of Landsat Type Satellites

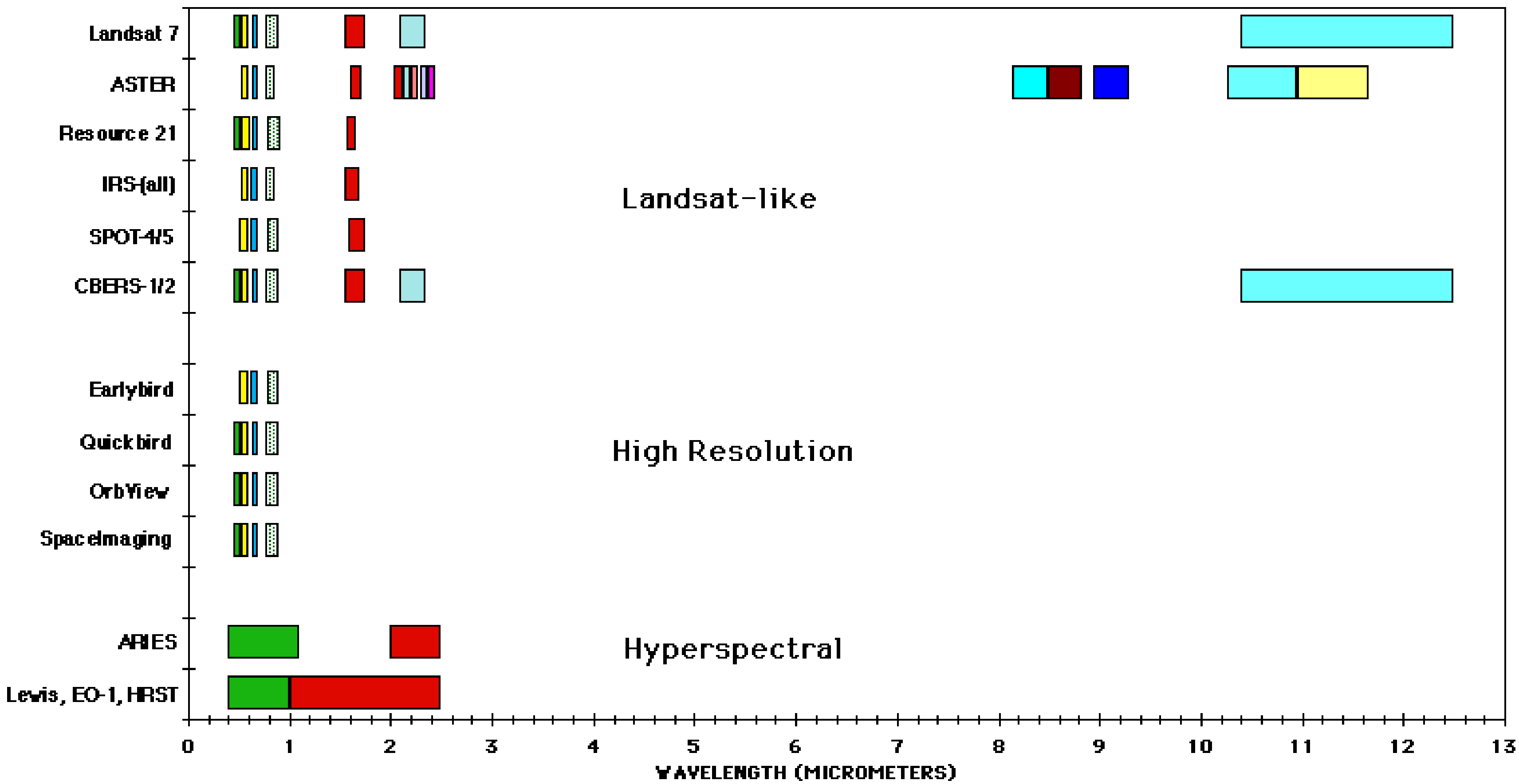

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Figure 8:
Spatial/Spectral Resolution of Land Observation Satellites

SPECTRAL SPATIAL RESOLUTION SUMMARY

PROGRAM	SENSOR TYPES	RESOLUTION IN METERS									
		THEMATIC MAPPER BANDS								RADAR	
		PAN	VNIR				SWIR		TIR		
			1	2	3	4	5	7	6	res,band	
LANDSAT-LIKE											
IRS-1 C,D	M&P	6		23	23	23	70				
IRS-P5, IRS-2A	M			6,23	6,23	6,23	23				
Spot 4	M&P	10		20	20	20	20				
CBERS	M&P	20, 80	20	20	20	20	80	80	160		
Landsat 7	M&P	15	30	30	30	30	30	30	60		
EOS AM-1	M			15	15	15	6 bands @ 3(		5@90		
Resource 21	M		10	10	10	10	20				
HIGH RESOLUTION											
EarthWatch	M&P	3		15	15	15					
SpaceImaging	M&P	1	4	4	4	4					
EarthWatch	M&P	1	4	4	4	4					
Orbimage	M&P	1&2	8	8	8	8					
SPIN-2	P(f)	2,10									
West Ind. Space	P	1.5									
West Ind. Space	P	1									
IRS-P6 (CARTOSAT-1	P	2.5									
HYPERSPECTRAL											
TRW Lewis	H&P	5	128 bands @ 30				256 bands @ 30				
EO-1	H&M		128 bands @ 30				256 bands @ 30				
HRST	H	5	210 bands @ 30								
ARIES	H	10	32 bands @ 30					32@30			
RADAR											
Radarsat	R									10-100	C
ENVISAT	R									25	C

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